THE FIRST ACCELERATION TEST OF POLARIZED PROTONS IN KEK PS BOOSTER

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ABSTRACT

Depolarization of the polarized proton beam accelerated in the 500 MeV booster was investigated as the first step of polarized proton acceleration in the KEK proton synchrotron. Beam polarization was measured in the 20 MeV beam transport line from the linac to the booster and in the main ring at the injection energy of 500 MeV. About 40 % of the linac beam polarization was kept in the main ring. This acceleration test encouraged us to proceed with this acceleration program.

INTRODUCTION

The project of polarized proton acceleration in the KEK 12 GeV proton synchrotron (PS) began in the fiscal year 1980. After the constructions of 750 keV pre-accelerator and the 750 keV beam transport line for the polarized H^- beam, the first acceleration test was performed in 1983 and depolarization in the 500 MeV booster synchrotron was investigated as the first step of this program.

The polarized H^- beam is produced in the high current polarized H^- ion source by a charge-exchange reaction with Na vapor which is optically pumped by dye lasers1). The polarized H^- beam is converted to the polarized proton beam in the booster by a charge-exchange injection through a thin carbon target of 120 $\mu g/cm^2$ for the electron stripping. The polarized proton beam is accelerated up to 500 MeV in the booster and then injected into the main ring.

Polarization of the polarized proton beam depolarizes during acceleration in the synchrotron by crossing depolarizing resonances. In the 500 MeV booster of the KEK PS, two strong depolarizing resonances must be crossed during acceleration from 20 MeV to 500 MeV. It is difficult to measure the depolarization of each depolarizing resonance independetly in the booster because the booster is a rapid cycling synchrotron of 20 Hz and the accelerated beam is sharply bunched (several tens nsec). Thus beam polarization was measured at 20 MeV in the beam line from the linac to the booster and at 500 MeV in the main ring by using the coasting beam for the investigation of depolarization in the booster. One of two strong depolarizing resonances in the booster is imperfection resonance due to vertical closed orbit distortion (COD) and the other is intrisic resonance due to vertical betatron oscillation. Thus each resonance can be investigated by varying vertical COD or vertical beam size in the measurement of depolarization during acceleration. For this purpose the fast rotary beam scraper which reduces the vertical beam size to any size at any energy during acceleration2) and the pulsed vertical deflection magnet which generates the maximum vertical COD of about 7 mm (rms) were installed in the booster.

DEPOLARIZING RESONANCES IN THE BOOSTER

Both the booster and the main ring of KEK PS are strong focusing synchrotrons and therefore strong depolarizing resonances are expected during acceleration3). Such depolarizing resonances occur at the resonance conditions of $\gamma G = nN \pm \nu_z$ for intrinsic resonance and $\gamma G = n$ for imperfection resonance. Where γ is Lorentz factor, ν_z is vertical betatron oscillation frequency, N is the superperiodicity of the machine, n is an integer and $G = g/2-1$. The polarization of the beam after crossing a depolarizing resonance is given by4)

$$P = P_0(2e^{-\pi\varepsilon^2/2\alpha} - 1) \quad ,$$

where P_0 is the initial polarization before crossing the resonance, ε is the resonance strength and α is the crossing speed for the resonance.

$$\alpha = (\dot{\gamma}G \pm \dot{\nu}_z)/\omega_0 \qquad \text{(for intrinsic resonance)} \ ,$$

$$\alpha = \dot{\gamma}G/\omega_0 \qquad \text{(for imperfection resonance)} \ ,$$

ω_0 is the revolution frequency of the circulating beam in the accelerator. The resonance strength ε is proportional to the amplitude of vertical betatron oscillation for intrinsic resonance and is proportional to vertical COD for imperfection resonance. Depolarization is small for small ε^2/α as in the case of weak resonance or rapid resonance crossing. On the other hand polarization flips for large ε^2/α . Therefore small depolarization is also expected by spin-flip in crossing the strong depolarizing resonance ($P \simeq - P_0$ $\varepsilon^2/\alpha >> 1$)5).

In the booster of KEK PS, two strong depolarizing resonances, one intrinsic resonance ($\gamma G = \nu_z$) at about 260 MeV and one imperfection resonance ($\gamma G = 2$) at 108 MeV, must be crossed during acceleration. Figure 1 shows the calculated resonance strengths of strong depolarizing resonances. The maximum amplitude of vertical betatron oscillation corresponding to the maximum vertical acceptance of 49 π mm mrad at 20 MeV and adiabatic damping of the betatron oscillation are assumed in this calculation. The strengh of intrinsic resonance is so strong that the spin flips almost completely in passing through the resonance. The imperfection resonance is calculated for the vertical COD of 1 mm (rms) and 5 mm (rms), respectively. Large depolariza-

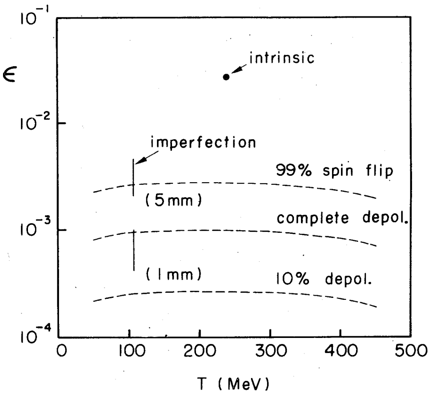

Fig. 1 Strength of depolarizing resonance in the booster.

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tion is expected even if COD is corrected to less than 1 mm. On the other hand spin-flip seems to be feasible if COD is larger than 5 mm.

POLARIMETERS

Polarization of the polarized proton beam is measured at 20 MeV beam line and at the main ring. Polarization of the linac beam is measured by the 20 MeV polarimeter which is placed in the scattering chamber of 655 mm in diameter installed in the 20 MeV beam line from the linac to the booster. The left-right asymmetry of elastic scattering events at a laboratory angle of 90° from proton-carbon scattering is measured by using a carbon fiber target of 100 μm in diameter. The detector consists of a pair of 1500 μm surface barrier SSD's and a double slit with 5 mm diameter hole as shown in Fig. 2. The distance between the target and SSD is 235 mm.

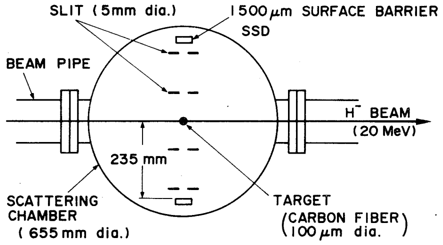

Fig. 2 20 MeV polarimeter.

An internal polarimeter (the main ring polarimeter) is installed in the long stright section II-2F of the main ring to measure the absolute polarization of circulating beam. It consists of a polyethylene string target and the forward and backward scintillation counter telescopes. The polarization is measured from the asymmetry of proton-proton elastic scattering. Figure 3 is the schematic of the main ring polarimeter. The scattered events are detected by two forward telescopes of 3 m in the maximum length and two backward telescopes of 55 cm in the maximum length. The elastic event is identified by the coincidence of the forward scattered proton and the backward one. The detection angle and the distance between scintillators and the target are adjusted to measure the asymmetry at the momentum transfer of $t = -0.15\ (\mathrm{GeV}/c)^2$ for the energy range from 500 MeV to 7 GeV. The coplanarity of scattered and recoil protons is checked to separate the proton-proton elastic scattering from proton-carbon reactions in the polyethylene target. Two targets are mounted in the scattering chamber: one is a polyethylene string of 150 μm in diameter and the other is a carbon fiber of 220 μm in equivalent diameter. Each target can be flipped into the beam independently. The carbon target is used for the subtraction of the background events from the carbon in the polyethylene.

The beam polarization was measured in the main ring with the coasting beam at 500 MeV. The coplanarity measurement shows that the elastic events are clearly observed and the background rate is less than a few percents at 500 MeV. The beam polarization in the main ring is measured in a few minutes with the statistical accuracy of $\lesssim$ 2 %. The asymmetry of the polarimeter measured by the unpolarized beam is less than 0.2 %. The details of the main ring polarimeter is reported elasewhere6).

SUMMARY AND RESULTS

Depolarization in the booster synchrotron was studied as the first step of polarized proton acceleration in the KEK PS. The intensities of polarized proton beam at the various stages of the accelerator were

ION SOURCE($H^-\uparrow$,750 keV) 5-10μA(pulse duration 75μsec),
LINAC ($H^-\uparrow$, 20 MeV) 0.5-1μA(pulse duration 75μsec),
BOOSTER ($p\uparrow$,500 MeV) 1 - 3 × 10^8 p/bunch ,
MAIN RING ($p\uparrow$,500 MeV) 1 - 2 × 10^8 p/bunch .

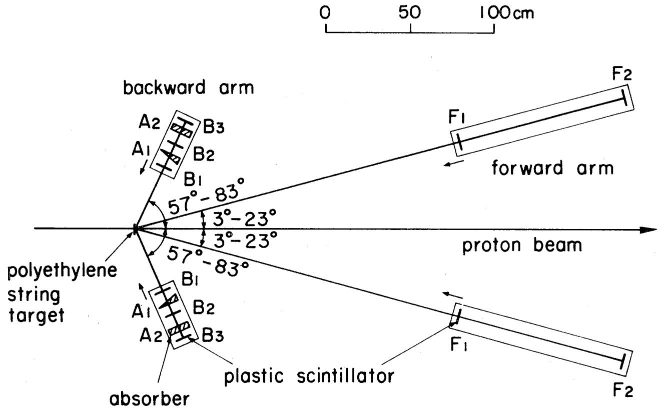

Fig. 3 Main ring polarimeter.

Since the study was just after the summer long shutdown, we had many troubles in the machine operation and the beam intensity after the linac was remarkably lower than expected one.

The main purpose of the first acceleration test was to investigate depolarization in the booster. We have not installed any equipment to reduce the depolarization in the booster because small depolarization by spin-flip is expected for two strong resonances. The polarizations of the polarized beam at 20 MeV and 500 MeV were

LINAC P(LINAC, 20 MeV) = 47 ± 6 - 56 ± 8 % ,
MR P(MR, 500 MeV) = 12 ± 2 - 15 ± 2 % .

Thus about 25 % of the linac beam polarization was kept in the main ring.

P(MR, 500 MeV)/P(LINAC, 20 MeV) $\sim$ 25 % .

In order to investigate the resonance strength, the dependences of the beam polarization on vertical beam size and on vertical COD in the booster were measured. Figure 4 is the dependence of the polarization on vertical beam size. Beam size was varied by using the fast rotary beam scraper which scraped the beam before crossing the intrinsic resonance $\gamma G = \nu_z$. This result shows that spin is flipped by passing through this resonance in the booster until the vertical beam emittance decreases to about 1/100 of the usual one. Thus the strength of intrinsic spin resonance is strong enough for the resonance crossing by spin-flip. If vertical beam size is blowed up to 1.5 - 2 times by the RF-knock out method or so, spin-flip becomes more complete near the beam center.

Figure 5 shows the measured polarization vs. the excitation current of the vertical deflection magnet which produces vertical COD. When the excitation current was negative, polarization was flipped by crossig the imperfection resonance. On the other hand polarization was kept without spin-flip in passing through this resonance at the excitation current of 169 A. The measured polarization in the main ring is negative at this current because spin is flipped by intrinsic resonance only. This result shows that the vertical COD in the booster is large enough to pass through imperfection resonance by spin-flip without the excitation of the vertical deflection magnet. At the excitation current of 169 A, depolarization is small since the second harmonic of the vertical COD is reduced by the deflection magnet.

An important problem has been left. The measurement shows that spin was almost completely flipped by two strong resonances ($\gamma G = 2$, $\gamma G = \nu_z$) as expected from the calculation. What is the other cause of depolarization in the booster ? We aimed to investigate the $\gamma G = 5 - \nu_z$ resonance at about 450 MeV due to the symmetry breaking of the machine. Toward the top energy the crossing speed for this resonance decreases since the magnet field of the booster varies sinusoidally. Thus in order to increase the crossing speed for the $\gamma G = 5 - \nu_z$ resonance, the resonance energy was decreased by changing ν_z with the excitation of a correction quadrupole magnet. Figure 6 shows the dependence of the polarization on the excitation of the correction quadrupole magnet. Polarization of about 1.5 times was obtained at the excitation current of 60 A. The crossing speed for this resonance increases about 10 % at this current. Polarization in this figure is relatively low because the Na vapor was trapped in the polarized ion source by sudden stop of electric power with the earthquake. If we had no such happening, polarization would reach 20 - 25 %. This result shows that about 40 % of the linac beam polarization is kept in the main ring by this small change of ν_z. That is,

$$P(MR, 500\ MeV)/P(LINAC, 20\ MeV) \sim 40\ \%\ .$$

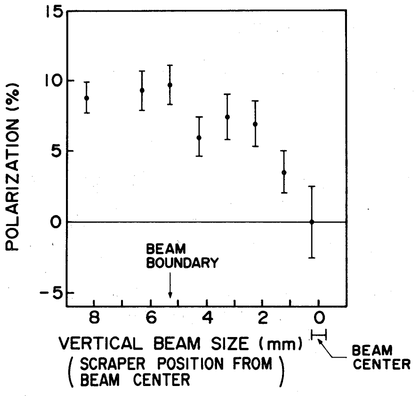

Fig. 4 Dependence of beam polarization at 500 MeV on the vertical beam size in the booster.

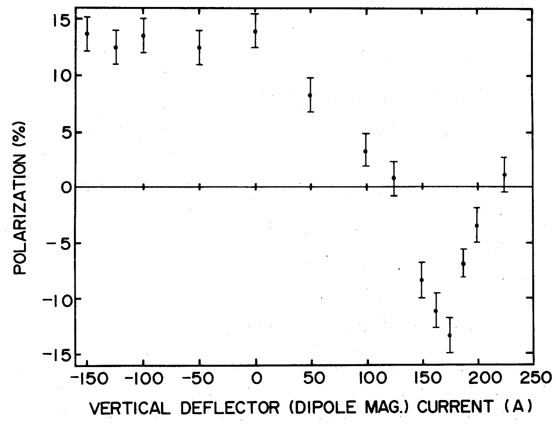

Fig. 5 Dependence of beam polarization at 500 MeV on the excitation current of the vertical deflection magnet in the booster.

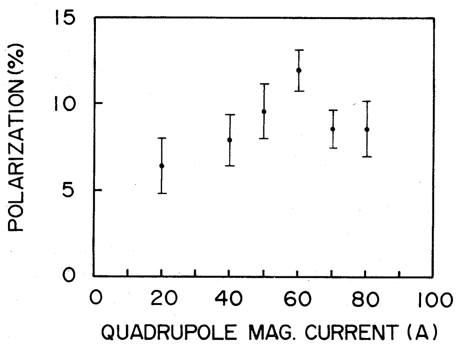

Fig. 6 Dependence of beam polarization on the excitation current of the correction quadrupole magnet.

Depolarization by other weak spin resonances are not so large because the sextupole field, which was applied by a small correction sextupole magnet, was not effective for depolarization. It is expected that the weak resonance due to the symmetry breaking of the machine causes large depolarization. Such depolarization in the booster will be solved by tune jump using the pulsed quadrupole magnets which will be installed in 1984.

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